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THE TREATMENT OF LIME-INDUCED CHLOROSIS WITH IRON SALTS

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The leaves of some plants when growing in soils containing an excess of lime become more or less yellow. This yellow condition is known generally as chlorosis, and when caused by an excess of lime in the soil, as lime-induced chlorosis. Lime in excess interferes with the absorption and utilization of iron by the plant. The failure to receive a normal iron supply results in leaves not forming the full amount of the green leaf pigment known as chlorophyll.

Lime-induced chlorosis usually appears first on the younger portions of the more rapidly growing shoots, and in perennials it spreads, during the following years, to older parts of the plant. In annual plants it is usually most severe on younger portions of the plant and may involve only a small part or nearly all of the plant. Light attacks usually do not cause much injury; but in severe attacks the plant may be severely stunted, fail to blossom or fruit, drop its leaves early, and it usually dies prematurely.

Soils containing an excess of lime usually contain also an abundance of iron but in a form insufficiently available to many plants. It has proven generally impracticable, thus far, to make the iron in the soil available, or to increase the amount of available iron present by the surface addition of fertilizers containing iron. The presence of excess lime in the soil quickly renders applied iron insoluble and unavailable. The only practicable, immediate cure for lime-induced chlorosis is to apply iron in suitable form and amount directly to the plant.

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It has long been known that lime-induced chlorosis can be remedied by direct application of iron to the plant. E. Gris,[2] in 1843 in France, first found that iron sulfate applied to chlorotic plants through roots or leaves caused them to become green. Since that time treatment of chlorosis has been more or less common in Europe. The applications have been made by spraying the leaves or by introducing the iron in suitable form directly into the roots, trunk, or branches of the plant.

The occurrence of yellow leaves during the growing season may be due to several other causes than an excess of lime. And it is not possible by an examination of the affected leaves to recognize the cause of yellowing. If the cause is an excess of lime this may usually be easily determined by an examination of the soil in which the tree roots are growing.

EXAMINING THE SOIL FOR LIME

A simple and often sufficient determination of the presence of lime may be made by pouring some muriatic acid on to the soil. If it foams strongly it probably contains lime in sufficient amount to cause chlorosis. The lime may not be present in the surface soil so it is necessary to examine it at various depths. This may be done most easily by boring with a soil auger or tube, keeping the soil from different depths separate and applying acid to each sample. The lime is often found near the surface but in some cases it may be necessary to sample to a depth of six feet or more. If no evidence of lime is obtained by such an examination the yellowing is probably due to some other cause. For a more accurate determination samples of the soil may be taken to a chemist. Any lime content of one per cent or over is likely to cause chlorosis of certain trees, especially pear, and a content of one-half to one per cent may be viewed with suspicion.

The more common, commercially-cultivated trees which show lime-induced chlorosis are pear, apple, quince, peach, apricot, prune, plum, cherry, walnut, orange, and lemon. Raspberries also suffer severely. Among ornamental plants eucalyptus, acacia and many other trees and shrubs are known to show chlorosis in high-lime soils. Pear trees grafted on Japanese or quince rootstocks develop chlorosis on high-lime soils much more quickly and severely than do those on French stocks. Stone fruits on myrobalan stocks generally show little or no chlorosis, while peaches and apricots on peach stocks may suffer severely. Observations on the effects of other stocks are not available.

[2] Gris, E. Nouvelles experiences sur l'action des composes ferrugineux soluble, appliques a la vegetation, et specialement au traitment de la chlorose et de la debilite des plantes. C. R. Acad. Sci. (Paris) 17:679. 1843.

TREATING THE TREE

There are four successfully used methods of treating plants with iron salts for lime-induced chlorosis: spraying, trench applications, solution-injection, and dry-salt treatment.

Spraying.—Spraying iron solution on the leaves has not proved to be commercially successful with fruit trees, on account of difficulties in securing good distribution on the leaves and because repeated sprayings are necessary during the growing season as new leaves develop. With few plants to be treated, spraying may easily be used. A solution of ferrous sulfate (copperas) one ounce per gallon of water, with the addition of one teaspoonful of liquid glue as a spreader, and a suitable sprayer, is all that is required. The spraying should preferably be done very late in the day so that the solution will not dry on the leaves and the iron may be absorbed during the night. The leaves should be thoroughly covered by the spray. The concentration of the iron solution mentioned has been found satisfactory for fruit trees with full-grown leaves; it may have to be reduced for tender foliage. The spraying should not be done while the plant is in bloom because of probable injury to flower parts. Limited trial applications should be made on plants where no previous experience is available, followed by observations for a few days before general treatment is applied. The treatment lasts but one season.

The Trench Method.—In this method of treatment, introduced widely in Europe in 1886 by Sachs,[3] a well-known German botanist, trenches several inches wide are dug around the tree to a depth of one to two feet, and one to several feet from the base of the tree so as to expose many small roots. Ferrous sulfate (copperas), crushed so that the largest lumps are about one-half inch through, is strewn along the trench bottom. The amount to be used increases with the size of the tree. The dimensions of trenches and the amounts of iron salt to use for trees of different sizes are suggested in the first four columns of table 1. Modifications of the amounts of iron salt indicated may have to be made as a result of experience. After spreading the iron salt in the bottom the trench is refilled with soil and heavily watered.

The same treatment may be applied by boring holes in the soil with a soil auger, about two inches in diameter. These should be one to two feet deep and two to three feet apart, in one or more rings around the tree spaced from one to several feet distant from the

[3] Sachs, J. Das Eisen und die Chlorose der Pflanzen. Naturw. Rundschau 1:257–259. 1886.

trunk. The numbers and depths of holes and amount of iron salt per hole is indicated in the last three columns of table 1. The total dose per tree is the same as when applied in trenches. After putting the iron sulfate in holes water freely and fill with soil. This modification of the trench method was originated by Hendrickson in 1924.[4]

TABLE 1

TRENCHES, HOLES, AND DOSAGE FOR TREATING NON-BEARING* TREES BY THE TRENCH METHOD

Diameter of tree, inches	Trenches, 8-12 inches wide		Amount of ferrous sulfate per tree, pounds	Auger holes, 2-inch diameter		Amount of ferrous sulfate per hole, ~~ounces~~ pounds
	Distance from tree, feet	Depth, inches		Number	Depth, inches	
1	1	12	1	4	12	0.25
2	1	12	2	4	12	0.5
3	1½	15	4	6	15	0.7
4	1½	15	6	8	15	0.7
5	2	15	10	10	15	1.0
6	2½	15	12	12	15	1.0
7	2½	18	14	14	18	1.0
8	3	18	16	16	18	1.0
9	3	18	18	18	18	1.0
10	3	18	20	20	18	1.0
15	4	18	30	30	18	1.0
20	5	18	40	40	18	1.0

*For bearing trees the dosage should be reduced to about one-half or two-thirds of that indicated in the table unless experience has shown there is no danger of injury to the blossoms.

The object in both the above applications is to bring the iron salt in contact with or very near to the smaller roots so that it may be absorbed before it becomes insoluble in the alkaline soil. The dosage indicated above is not intended to be fixed but is suggested as a trial dose. If it proves to be too large some burning and blackening of foliage will occur in the early spring, but usually it is not severe and does not affect the later leaves. Burning may be avoided by decreasing the amount applied. On the other hand, the dosage given may be too small or not well distributed and an incomplete cure may result. It is essential that the amount applied be sufficiently large and that it be well distributed on all sides of the tree, to get satisfactory results. The dosage suggested may serve as a general guide until experience is gained with the soil and trees at hand. Other iron salts than ferrous sulfate have not been extensively used in trench applications on account of expense.

[4] Hendrickson, A. H. A chlorotic condition of pears. Proc. Amer. Hort. Sci. 1924:87–90.

The application is preferably made in the late winter or spring just before leaves appear. It may be done after the leaves unfold but there is then much greater likelihood of burning the foliage and the dosage should be decreased to one-half, or less, of that indicated above. It will readily be seen that the treatment described above is expensive in labor, and also in iron salt since large amounts of it are required and most of that used does not reach the tree but is lost in the soil. It has been successfully used, especially on ornamental plants. It may be used where but few plants are to be treated and expense is not a serious consideration, and where there is objection to the wounding of trees involved in the methods to be described next. Some use has been made of the trench application in commercial orchards by plowing deep furrows near the tree rows and spreading iron sulfate in the furrows at the rate of 500 to 2,000 pounds per acre in the early spring before leaves appear. This has sometimes resulted in cures and sometimes in complete failure. When applied carefully in trenches, or in auger holes, with watering afterward, the results are generally good. Successful applications of iron sulfate to chlorotic raspberry plants have been made by using one to two pounds per ten feet of row in trenches or furrows several inches deep close to the base of the plants.

The Injection of Solutions of Iron.—In this method, also originated by Sachs, iron is introduced into the tree in solution in water. In the usual procedure any soluble iron salt such as iron sulfate (copperas), iron chloride, iron nitrate, ferrous or ferric citrate or tartrate, or iron ammonium citrate, is dissolved in water at the rate of one ounce per gallon. In trees up to six inches in diameter a single hole, one-fourth to three-eighths inch in diameter is bored about two-thirds to three-fourths through the trunk, with the bottom of the hole somewhat lower than the mouth. Into the hole is screwed tightly a short length of threaded pipe and above this a suitable reservoir is attached, directly, or by a rubber tube. Iron solution is placed in this reservoir in an amount determined by the size of the tree. Air must be displaced from the hole and connections in order to prevent blocking of flow and absorption of solution. This is readily accomplished by filling the hole and pipe with solution before attaching the reservoir. For larger trees, in order to secure good distribution of the iron solution, two or more such reservoirs are attached separately, to holes bored parallel to each other from one side of the tree and three to four inches apart; or to holes bored toward the center of the tree to a depth of four to six inches and at intervals of six to eight

inches around the tree. The latter arrangement of holes is preferable for trees with well-developed heartwood. The holes may also be bored in the larger roots or in the base of the trunk below the ground level, or in branches. The number and depth of holes per tree and the amount of solution for trees of different sizes are indicated in table 2. This table is intended only as a guide and may require modification according to experience. The solution of iron is gradually absorbed by the wood and passes mostly toward the branches. The rate of absorption may be hastened by raising the reservoir. Trees that exude sap or bleed from wounds cannot be injected during the season of bleeding. After treatment the holes are covered with grafting wax.

TABLE 2

DOSAGE AND HOLES FOR TREATING NON-BEARING* CHLOROTIC TREES BY THE SOLUTION-INJECTION METHOD

Tree diameter, inches	Holes, ⅜-inch diameter		Amount of solution†, pints per tree
	Number	Depth, inches	
2	1	1½	½
3	1	2	1
4	1	3	1½
5	1	4	3
6	1	5	5
7	2	5	6
8	2	6	7
9	2	7	8
10	2	8	10
15	3	10–12	15
20	4	10–17	20

* For bearing trees the dosage should be reduced to about one-half or two-thirds of that indicated in the table unless experience has shown there is no danger of injury to the blossoms.

† Based on a solution of one ounce per gallon.

This treatment gives best results if applied during the dormant season when leaves are absent. If applied during the leafy season the iron solution passes rapidly to the leaves and may cause severe burning and loss of part or all the leaves and of the blossoms or fruit. The treating of evergreens by this method should be done preferably in winter when absorption will be slower.

In all treatments by injection of iron solutions when leaves are present the strength of the solution should be reduced to about one-fourth that used in treating leafless trees and the total dose per tree should be correspondingly reduced to avoid injury to the leaves. Successful results with this method of treatment are dependent upon

applying a sufficiently large dose and in securing good distribution of the iron salt by applying through a sufficient number of holes.

Dry-Salt Treatment.—It was found by Mokrzecki[5] to be unnecessary to dissolve the iron salts in water before introducing them into the tree. Wood contains about fifty per cent water and if a soluble iron salt is placed in a hole bored in live wood and the mouth of the hole sealed the salt absorbs water from the wood and dissolves and passes into the surrounding wood from which it passes to the branches with the sap stream. In applying this treatment ¼ to 7/16-inch holes are bored in the larger roots, in the trunk above or below the ground level, or in branches. The holes should be bored at intervals of three to four inches around the root, trunk, or branch and from one to three inches deep. In the bottom of each hole is placed from 1/100 to ⅛ ounce of ground iron salt. The hole and the amount of salt used should be so proportioned that the mass of salt does not come closer than half an inch from the mouth of the hole, in order to avoid burning of the bark around the hole by the salt. The mouth of the hole is then covered with a suitable wax. The number and depth of holes and dosage for trees of different sizes is shown in table 3.

TABLE 3

Dosage and Holes for Treating Non-bearing* Chlorotic Trees by the Dry-salt Method

Tree diameter, inches	Holes			Amount of salt	
	Number	Diameter, inches	Depth, inches	Per hole, ounces	Per tree, ounces
1	1	¼	⅝	0.01	0.01
1½	1	¼	1	0.02	0.02
2	1	7/16	1¼	0.05	0.05
3	3	7/16	1¼	0.03+	0.1
4	4	7/16	1½	0.05	0.2
5	5	7/16	1¾	0.06	0.3
6	6	7/16	2	0.08+	0.5
7	7	7/16	2	0.08+	0.6
8	8	7/16	2½	0.09	0.7
9	9	7/16	2½	0.09	0.8
10	10	7/16	2½	0.1	1.0
15	15	7/16	3	0.1	1.5
20	20	7/16	3	0.1	2.0

* For bearing trees the dosage should be reduced to about one-half or two-thirds of that indicated in the table unless experience has shown there is no danger of injury to the blossoms.

Table 3 was developed from experience in treating pear trees. It may or may not apply to other trees of similar size. The dosage

[5] Mokrzecki, S. A cure for chlorosis. Gard. Chron. 35:36. 1904.

should be proportional to the weight of the tree. The reference of dosage to diameter is convenient but will apply only to trees of similar height. For trees which are much taller than pear trees for a given diameter, such as eucalyptus, the dosage shown above may be safely doubled. In general the table should be considered only as a general guide, so far as dosage is concerned. It is adapted to pears, but other trees may require larger or smaller doses.

The tools for applying the treatment are few: an ordinary brace or breast drill; ordinary wood bits, ¼-inch for trees less than two inches in diameter, $\frac{7}{16}$-inch for all larger sizes; a bit extension two to three feet long; a ⅜-inch thin-walled metal tube about eight or nine inches long, with a close-fitting metal plunger about three inches longer than the tube, for placing the powdered salt in the holes; a similar tube of ¼-inch diameter with plunger for small trees; and a pot of wax. A ⅜-inch tube with walls $\frac{1}{32}$ inch thick holds about $\frac{1}{20}$ ounce of ground iron salt per inch of length when moderately packed; a ¼-inch tube holds about $\frac{1}{100}$ ounce per half inch of length. If a large number of trees are to be treated a powder 'gun' may be constructed according to the diagram (fig. 1*H*). This instrument saves much time in placing the powdered salt in the holes. Boring the holes somewhat downward instead of horizontally also facilitates the placing of the powdered salt and prevents it from spilling back on to the bark.

If the applications are to be made below ground level soil is removed from around the base of the trunk to a depth of three or four inches. After covering the holes with wax the soil is replaced immediately if soft grafting wax is used; or several hours later if emulsified asphalt is used, to allow the emulsion to dry somewhat and stick to the bark. In all applications the powdered iron salt is preferably placed in the holes and these sealed within a few hours after boring; the holes should not be allowed to dry out inside.

Any sufficiently soluble iron salt will bring about a cure of chlorosis when applied in the above manner. Among many salts tried experimentally, ferrous and ferric citrate have given the best results. The latter salt is manufactured only for the drug trade and retails for about $1.25 to $1.75 per pound. It may be obtained through any drug or chemical supply house. Ferrous citrate is manufactured in a technical grade especially for treating chlorotic trees. It may be obtained from chemical supply houses for about 75 cents per pound under present market conditions. Both salts should be purchased ground to pass a 60-mesh-to-the-inch screen, and will keep indefinitely

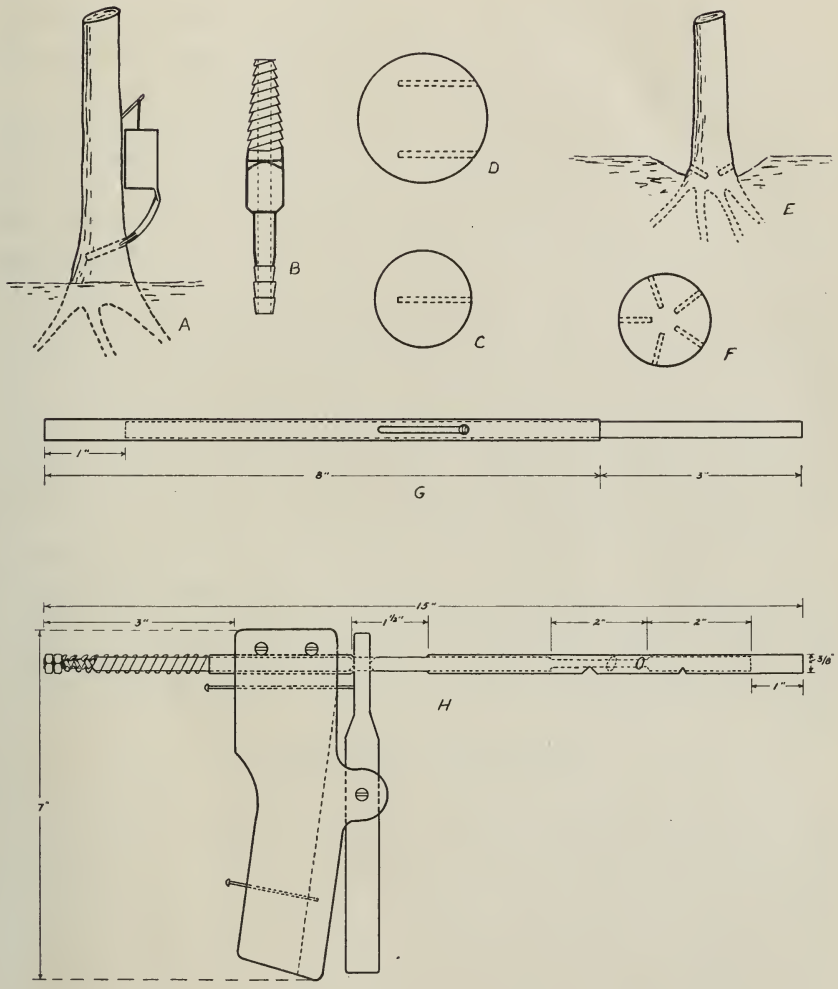

Fig. 1.—*A*, Injection apparatus attached to tree; *B*, threaded, tapered, and bored screw for injection of solutions; *C*, *D*, showing manner of boring holes for injection of solutions; *E*, *F*, showing manner of boring holes for dry-salt treatment; *G*, plain tube with plunger for placing ground iron salts in holes; *H*, 'Gun' for placing ground iron salt in holes.

if kept dry. Other iron salts such as iron chloride, iron sulfate (copperas), iron nitrate, iron tartrate, and iron ammonium citrate may be used for treating trees. Some of them, however, are less convenient to handle on account of becoming sticky through absorbing moisture from the air, and none of them have, in experimental tests, given as uniformly good results as ferrous or ferric citrate.

Soft grafting wax suitable for underground use is made by melting 4 pounds rosin, 2 pounds beeswax, and mixing with an equal volume of linseed oil; or it can be made by melting hard grafting wax and mixing with about one-half its volume of linseed oil. The wax handles easily with a paddle. For use above ground an ordinary grafting wax softened by heating may be used. The wax should not be so soft that it runs into the hole. Emulsified asphalt preparations serve well if suitably modified, but do not stick to the tree so well in wet weather and often contract away from the side of the hole when exposed for long periods. For use they are mixed with sufficient flour or starch to give the desired consistency for handling with a paddle and to prevent running into the holes; and a little crude creosote or carbolic acid is added to prevent the growth of molds.

In treating by injection of solutions or by the dry-salt method it will be necessary to sterilize instruments before each operation to guard against spreading infectious diseases such as pear blight, citrus gummosis, etc. The usual solution for this purpose is one part of corrosive sublimate and one part of mercuric cyanide to 500 parts of water.

RESULTS OF TREATMENT

If maximum doses are used, the trench, injection and dry-salt treatments will last about three years on pears. The first year, after treatment, the leaves should be fully green over all the tree. An occasional twig or larger branch may be yellow. During the second and third year chlorosis gradually shows again, coming on first at the tips of the more rapidly growing shoots, and may involve most of the length of the shoots the third year. Spur leaves usually remain green throughout the period so that fruiting is not affected directly. Shoot growth is strongly stimulated by treatment of trees that have not become severely stunted.

The best results by the trench, solution-injection, and dry-salt methods are obtained when the treatment is applied during the dormant season when leaves are absent. Treatments may be made during the leafy season but no effect except greening of the leaves is produced the first season when application is made later than June.

In re-treating, the previously bored holes should be avoided. Some wood is killed near the hole and above and below it. Absorption of solution or of dry-salt applications does not occur well through dead wood. The holes are overgrown with new wood and bark usually the first year after treatment so that their location can be ascertained at re-treatment time only by boring; after locating one the others can easily be avoided. The amount of wood removed by boring and killed by the chemical is not large, amounting to about 20 per cent of the cross section at the level of boring, and is about offset by a single year's growth. No case of breakage resulting from boring has thus far occurred in several years of treatments including several renewal treatments.

When leaves appear the first time after treatment with the proper dose there is usually some burning and blackening of the first small leaves that come from the bud. These fall in a short time and succeeding leaves are green and uninjured. When overdosage has occurred the burning of leaves may extend to later-appearing spur leaves and even to shoot leaves. Killing of branches is unusual with overdosage because the leaves which are killed carry away much of the excess salt.

There is some difference among pear varieties in likelihood of injury by overdosage. Bartlett and Hardy appear to be least liable to be injured; Winter Nelis most liable. The other varieties so far as is known appear to be slightly more sensitive than Bartlett and Hardy. The dosage suggested in table 2 applies to all varieties tested except Winter Nelis in which one-half to two-thirds of the indicated dose should be used.

In treating bearing trees some cases of blossom burning have occurred, especially with Winter Nelis. For bearing trees the dosage should be reduced to one-half or two-thirds that given in the tables unless experience has shown that there is no danger. When correct treatment is applied the effects on the crop of chlorotic trees which are still bearing is evident the first year in a heavier set of fruit amounting to as much as 100 per cent increase over untreated trees. The full effects of treatment on bearing are not shown until the second year when fruit buds formed during the first year of treatment may result in increases of fruit of several hundred per cent, over untreated trees. Severely injured, stunted trees, which have ceased bearing before treatment, become green as a result of treatment but may not resume bearing or growth for some time. It is doubtful whether or not it is economical to retain and treat such trees.

On trees other than pears no extended experience is available. The last three methods of treatment as described have been used successfully on peaches, plums, prunes, cherries, walnuts, eucalyptus and many other ornamental shrubs and trees. With slender-stemmed, woody plants, such as very young trees, raspberry bushes, and herbaceous forms, only the trench method can be economically and safely used. The cost of treatment varies principally with the size of the trees; larger trees require more iron salt and more labor for application. No figures are available as to cost of the trench and solution-injection treatments. Treatments on a commercial scale with good tools by the dry-salt method have been found to cost about one cent per hole for iron salt, wax, and labor, so that trees five inches in diameter would cost five cents and trees ten inches in diameter ten cents per tree. A total of about 75,000 pear trees have been successfully treated by the dry-salt method, mostly by the growers themselves.

None of the described methods are to be looked upon at the present time as permanent practices for the prevention of lime-induced chlorosis. They are rather to be considered as temporary remedies to be used to recover on an already heavy investment. A more satisfactory and possibly permanent remedy should be sought through the soil. A promising method of attack along this line has recently been described by Wallace[6] in England. It consists simply of "grassing down" the orchard with alfalfa, clover, or grass and fertilizing if necessary with nitrogen, applied preferably as ammonium sulfate to meet the extra demand of a double crop. A satisfactory cure required three years. This method is under trial by a few growers in California. Whether or not it can be satisfactorily used under dry summer conditions remains to be demonstrated; but the possibility demands consideration as offering a permanent solution to the problem of lime-induced chlorosis.

[6] Wallace, T. Investigations on chlorosis of fruit trees. IV. The control of lime-induced chlorosis in the field. Jour. Pom. and Hort. Sci. 7:251–269. 1929.